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A comparison between the consumption of polyethylene pyrolysis oils and diesel to supply a generator powered by a single cylinder diesel engine

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Abstract— **The paper presents data related to the results about the fuel consumption following the testing of a commercial diesel fuel and a fuel obtained by chemical recycling of polyethylene waste, which fueled a generator powered by a single cylinder diesel engine air cooled. The experimental results showed that using synthesized polyethylene-based fuel, the consumption of fuel from polyethylene was smaller compared to the consumption when using commercial diesel fuel.**

Index Terms— **Polymers waste, Pyrolysis, Fuel, Diesel engine..**

I. Introduction

Plastic materials recycling methods depend on the type of the polymers (thermoplastic or duromers) and their purity. For mechanical recycling, rigorously sorted plastic materials are needed, for chemical recycling or recycling for energy recovery mixed plastic materials can be used, but the condition for processing must be appropriate to the composition of waste [1-3].

Chemical recycling allow the obtaining of raw materials and fuels resembling gasoline or diesel [4-8] depending on the polymers.

When Plexiglas (Poly(methyl methacrylate) - PMMA) or Polystyrenes (PS) is use for pyrolysis, a high yield in monomers (methyl methacrylate [9] and styrene respectively) can be reached. In the case of polyolefin, following pyrolysis a complex mixture of organic compounds containing mainly C and H can be obtained resembling the composition of commercial transportation fuels [8].

Pyrolysis (thermolysis), is a process that involved thermal treatment in the absence of oxygen of polymer waste, with or without catalysts, leading to the formation of smaller molecules including monomers used as raw materials for new polymers (monomers), fuels or petrochemical [4].

Studies regarding PE pyrolysis showed that the degradation product composition depends on the type of PE (HDPE – High Density Polyethylene, LDPE – low density polyethylene, LLDPE – Linear Low Density Polyethylene, XLDPE – Cross-Linked Low Density Polyethylene), temperature of pyrolysis, pressure, catalysts and the number of degradation stages [6].

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Pyrolysis process applied to PE conduct to the formation of oils, gases and solid residue.

When LDPE and LLDPE are used in pyrolysis processes a higher yield in liquid products is obtained when compared to HDPE or XLDPE.

Catalysts promote (in the case of LDPE) cracking reactions conducting to the formation of oils and gases in higher quantities, including aromatic hydrocarbons such as benzene, toluene, xylene and feedstock for petrochemicals [5-7].

Studies regarding PE pyrolysis were made systematically [5-8], but characterization and testing of degradation product as fuel for engines are quite rare [10-16].

Some papers presents the results obtained when pyrolysis product are used as blends with commercial diesel fuel [15, 18] for fueling diesel engines and study the pollutant emissions as a function of operating conditions [17, 18].

Other studies involved the use of blends of melted plastic waste and heavy oil for Diesel engine generator systems [14, 16].

Our team has been involved in research regarding both the obtaining of fuels [19-23] and monomers [9] by chemical recycling through pyrolysis of polymers.

The novelty of our researches consists in the study of a fuel obtained from polyolefin in our laboratory and testing of synthesized fuel in diesel engine air-cooled, without any modification, without blending with commercial diesel fuel. We determined hourly consumption and engine speed variation with and without load.

II. Materials and methods

A. The obtaining of the fuel

Details regarding the pyrolysis process applied for fuel production starting from PE were presented in our previous studies [19-23] and involved the use of a homemade laboratory installation.

B. Engine tests

A single cylinder, 4-stroke, air-cooled, direct injection diesel engine, model Kipor KM 186FAG, has been used for fuel testing.

The main specifications and technical data for the diesel engine are: cylinder bore x stroke - 86 x 72 [mm]; displacement - 418 [cc]; rated speed of 3000 [rpm]; rated power of 5.7 [kW]; compression ratioof 19:1; starting system recoil and electric starter; rotating direction (viewed from flywheel) clockwise.

The tests were conducted on the engine running with and without load.

III. Results and Discussions

Following our previous studies one concludes that the properties of the oil obtained by thermal degradation of PE are close enough (in accordance with EN 590 regulation) with the properties of commercial diesel fuel [20], leading to the conclusion that the synthesized fuel can be used as it is or as mixtures with commercial diesel fuels, in diesel engines. During tests, the hourly fuel consumption was determined as a function of engine's load.

Determination of the hourly fuel consumption to the generator was done at idle and load progressively until it stops due to overload.

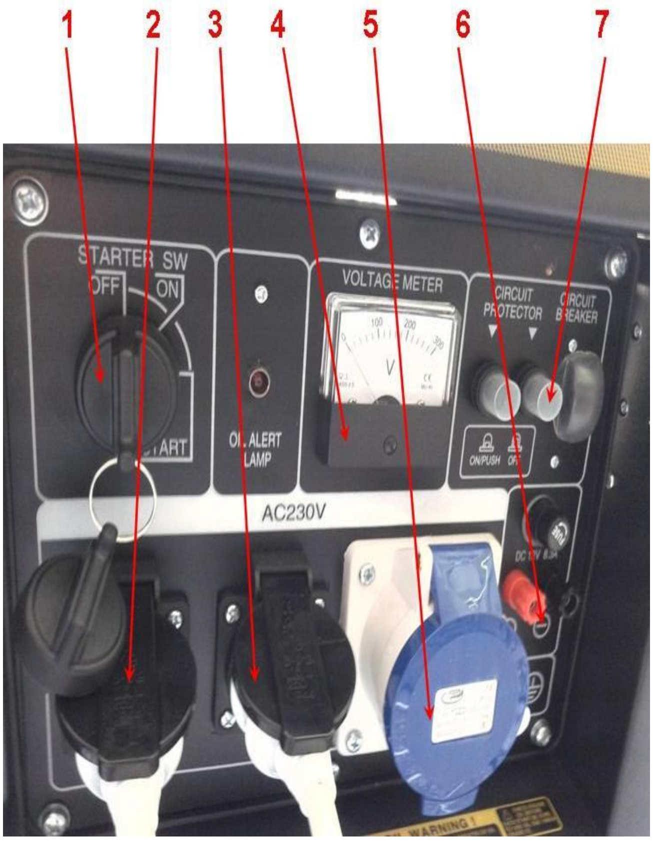

Figure 1: Command-control-protection panel and output power generator.
1 - start contact; 2 and 3 - sockets 220 VAC / 8.5 A;
4 - voltmeter; 5 - socket 220 VAC / 32 A;
6 - socket 12 VDC; 7 - overload protection circuit

In order to load the generator and to be able to achieve a progressive loading of the electrical generator, knowing that the command and control to the generator will preserve same values for the current frequency and voltage (220V and 50Hz) provided to the two sockets used for measuring (fig. 1) it have been designed and manufactured two identical assemblies (fig. 2).

The data obtained during the measurements are centralized in Tables 1 and 2.

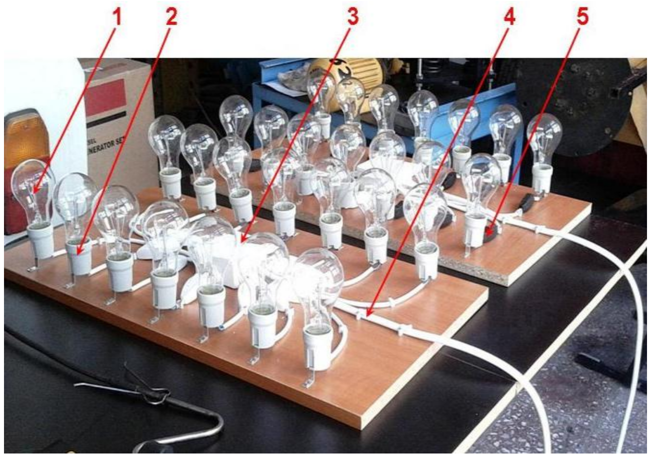

Figure 2: Mounting with resistive light bulbs.
1 - 200 W light bulb; 2 - ceramic socket; 3 - connection box; 4 - power cord; 5 - switch

Hourly fuel consumption

The determination of hourly consumption has been made by measurement the volume of consumed fuel in a time period and a specific load.

The test was timed, obtaining the time for fuel consumption, and in the final, the hourly consumption (c_h) has been calculated with the relation:

$$c_h = \frac{3600 \cdot v_\tau}{\tau}, [l/h] \quad (1)$$

where:

- τ is the time, in seconds, during which v_τ fuel has been consumed;

- v_τ - the volume, in liters, of the fuel consumed in the time interval τ.

After processing the results were drawn the following charts:

* hourly consumption as a function of load of the generator and their polynomial regressions for both fuels (fig. 3);

* engine speed as a function of load of the generator and their polynomial regressions for both fuels (fig. 4);

From the analysis of the graphic of the two tested fuels consumption as a function of load of the generator one can easily observe that when fuel the fuel obtained from polyolefin waste an average hourly consumption smaller with 14.4 % for the same load of the generator.

Using second order polynomial regression we obtained the curves of the variation of hourly consumption thus indicating a favorable differentiation for the experimental fuel (smaller consumption for the higher loads of the generator (3200 – 4800 W)).

Table 1: The data obtained during the tests with diesel.

Nr. crt.	Initial volume	Final volume	Consumption	Hourly diesel consumption	Length test	Load of the generator	Engine speed	Number of light bulbs 200 W	Remarks
	[l]	[l]	[l]	[l/h]	[s]	[W]	[rpm]		
1	0.4275	0.4025	0.0250	0.744	120.94	0	3260	0	-
2	0.4025	0.3715	0.0310	0.926	120.54	800	3240	4	-
3	0.3615	0.3275	0.0340	1.005	121.83	1600	3220	8	-
4	0.3275	0.2890	0.0385	1.162	119.31	2400	3170	12	-
5	0.2890	0.2430	0.0460	1.372	120.7	3200	3160	16	-
6	0.2430	0.1890	0.0540	1.608	120.89	4000	3150	20	-
7	0.1890	0.1300	0.0590	1.779	119.36	4400	3150	22	-
8	0.1290	0.0625	0.0665	1.984	120.69	4800	3140	24	-
9	0.371	0.363	0.008	2.355	12.23	5000	3110	25	Breaking overload at 12.23 s

Table 2: The data obtained during the tests with fuel obtained from polyethylene.

Nr. crt.	Initial volume	Final volume	Consumption	Hourly fuel consumption	Length test	Load of the generator	Engine speed	Number of light bulbs 200 W	Remarks
	[l]	[l]	[l]	[l/h]	[s]	[W]	[rpm]		
1	0.5000	0.4785	0.0215	0.640	120.88	0	3280	0	-
2	0.4785	0.4520	0.0265	0.790	120.72	800	3260	4	-
3	0.4520	0.4225	0.0295	0.871	121.92	1600	3240	8	-
4	0.4225	0.3895	0.0330	0.990	120.02	2400	3220	12	-
5	0.3895	0.3505	0.0390	1.170	119.97	3200	3205	16	-
6	0.3505	0.3045	0.0460	1.375	120.42	4000	3190	20	-
7	0.3045	0.2540	0.0505	1.521	119.54	4400	3190	22	-
8	0.2540	0.1975	0.0565	1.693	120.16	4800	3175	24	-
9	0.1975	0.1915	0.0064	1.892	12.18	5000	3140	25	Breaking overload at 12.18 s

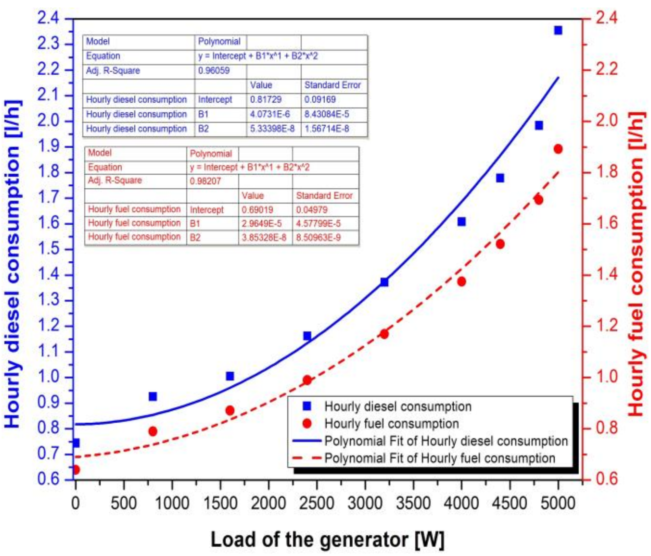

Figure 3: Hourly consumption as a function of load of the generator and their polynomial regressions for both fuels

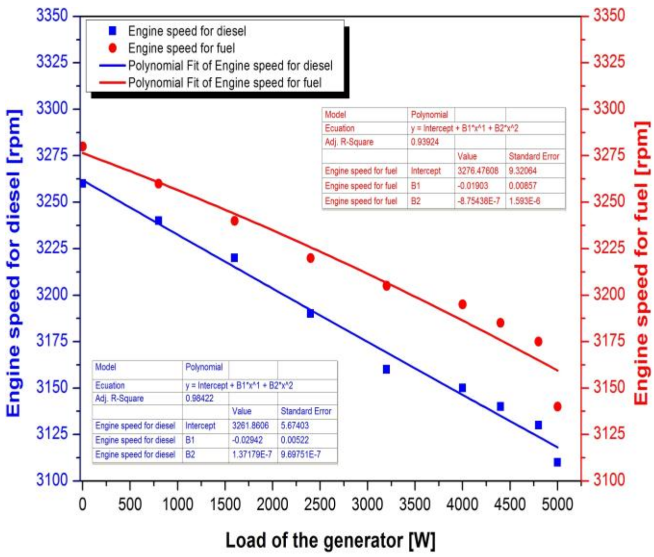

Figure 4: Engine speed as a function of load of the generator and their polynomial regressions for both fuels

The representation of the dependence of engine speed of the generator as a function of the load indicated small oscillations of 1.06 % of the measured speed rate for the two used fuels. Polynomial regression of the measured sped rate as a function of the generator load indicated the maintaining of higher speed rate of in the range of higher loads of the generator caused probable by the higher calorific power of the new fuel [23].

IV. Conclusions

An important advantage of the experimental fuel is the reduced hourly consumption comparing to the consumption of diesel commercial fuel.

Large scale application of chemical recycling of PE for fuel production can be a good alternative for solving the problems related to the impact of plastic waste on environment, leading to fossil fuel saving in conditions of proper engine efficiency, due to the high quality of pyrolysis product regarding combustion behavior.

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References

[1] Defra (Department for Environment, Food and Rural Affairs). "Energy from Waste, a Guide to the Debate." February 2014 (revised edition), Defra. Accessed june 06, 2015. https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/284612/pb14130-energy-waste-201402.pdf

[2] Aguado, J., Serrano, D. P., & San Miguel, G. (2007). European trends in the feedstock recycling of plastic wastes. Global Nest J, 9(1), 12-19.

[3] Association of Plastic Manufacturers in Europe (APME), An analysis of plastics consumption and recovery in Europe, Brussels (Belgium) 2004, Accessed june 06, 2015, http://www.plasticseurope.org/Document/plastics-in-europe---an-analysis-of-plastics-consumption-and-recovery-in-europe-2002-2003.aspx

[4] Bagri R., Williams P. T. (2002) Catalytic pyrolysis of polyethylene. Journal of Analytical and Applied Pyrolysis, 63(1), 29-41.

[5] Uddin, M. A., Koizumi, K., Murata, K., & Sakata, Y. (1997). Thermal and catalytic degradation of structurally different types of polyethylene into fuel oil. Polymer degradation and stability, 56(1), 37-44.

[6] Achilias, D. S., Roupakias, C., Megalokonomos, P., Lappas, A. A., & Antonakou, E. V. (2007). Chemical recycling of plastic wastes made from polyethylene (LDPE and HDPE) and polypropylene (PP). Journal of Hazardous Materials, 149(3), 536-542.

[7] Gobin, K., & Manos, G. (2004). Polymer degradation to fuels over microporous catalysts as a novel tertiary plastic recycling method. Polymer Degradation and Stability, 83(2), 267-279.

[8] Ng, S. H., Seoud, H., Stănciulescu, M., & Sugimoto, Y. (1995). Conversion of polyethylene to transportation fuels through pyrolysis and catalytic cracking. Energy & Fuels, 9(5), 735-742.

[9] Popescu, V., Vasile, C., Brebu, M., Popescu, G. L., Moldovan, M., Prejmerean, C., Trişcă-Rusu C., Cojocaru, I. (2009)." The characterization of recycled PMMA". Journal of Alloys and Compounds, 483(1), 432-436.

[10] Mani, M., & Nagarajan, G. (2009). Influence of injection timing on performance, emission and combustion characteristics of a DI diesel engine running on waste plastic oil. Energy, 34(10), 1617-1623.

[11] Mani, M., Nagarajan G., and Sampath S. (2010). "An experimental investigation on a DI diesel engine using waste plastic oil with exhaust gas recirculation." Fuel, 89(8), 1826-1832.

[12] Mani, M., Subash, C., & Nagarajan, G. (2009). Performance, emission and combustion characteristics of a DI diesel engine using waste plastic oil. Applied Thermal Engineering, 29(13), 2738-2744.

[13] Mani, M., Nagarajan, G., & Sampath, S. (2011). Characterisation and effect of using waste plastic oil and diesel fuel blends in compression ignition engine. Energy, 36(1), 212-219.

[14] Mitsuhara, Y., Soloiu, V. A., Nakanishi, Y.A, Yoshihara, Y., Nishiwak, K., Hiraoka M. (2001), "Application of New Fuel Produced from Waste Plastics and Heavy Oil to Diesel Engine", Transactions of the Japan Society of Mechanical Engineers. B: 67, 2618-2624.

[15] Moriya, S., Watanabe, H., Yaginuma, R., Matsumoto, T., Nakajima, M., Tsukada, M., & Isshiki, N. (2000). Studied of recycled fuel oil for diesel engine extracted from waste plastics disposals. In Energy Conversion Engineering Conference and Exhibit, 2000.(IECEC) 35th Intersociety (Vol. 1, pp. 510-515). IEEE.

[16] Nakanishi, Y., Yoshihara, Y., Hiraoka, M., Nishiwaki, K., Soloiu, V.A., Mitsuhara, Y. (2000). Application of a New Fuel Produced from Waste Plastics and Heavy Oil to Diesel Engine, Nippon Kikai Gakkai, Jidosha Gijutsukai Nainen Kikan Shinpojiumu Koen Ronbunshu, 16, 461-466.

[17] Santaweesuk, C., and Janyalertadun A. (2013). "Influence of Nozzle Pressure on Performance and Emission in Compression Ignition Engine Running on Distilled Waste Plastic Oil (DWPO).", International Journal of Environmental Science and Development, 4(1), 316-320.

[18] Jani, A., Patel, T., & Rathod, G.(2015). Effect of Varying Load on Performance and Emission of CI Engine Using WPO Diesel Blend, IOSR Journal of Mechanical and Civil Engineering, 12(2), 37-44

[19] Popescu, G. L.(2012). "Modeling as function of temperature of viscosity and density for blends of diesel fuel and thermally degraded polyethylene." Acta Technica Napocensis-Series: Applied Mathematics, Mechanics, and Engineering 55(4), 897-902

[20] Popescu, G.L.; Filip, N.; Popescu, V. (2011) „Research on the implementation of alternative fuels obtained from polymeric materials for agricultural tractors", Aktualni Zadaci Mehanizacije Poljoprivrede, 39, 39-51.

[21] Popescu, G. L., Filip N., and Popescu V.. (2015) "A comparison between diesel and fuel obtained from recicled waste plastics used for fueled diesel engines." INMATEH-Agricultural Engineering 45(1), 141-148.

[22] Popescu, G. L. (2012). "The influence of environmental temperature on the exhaust gases opacity from a single cylinder diesel engine powered by fuel obtained from polyethylene." INMATEH-Agricultural Engineering 37(2), 79-86.

[23] Popescu, G. L., FILIP, N., and Popescu V. "Research aiming simultaneously recycling of waste polyolefins by pyrolisis, in order to obtain some fuels for compression ignition engines." SMAT 2014 - SIAR Congress 3rd International Congress Science and Management of Automotive and Transportation Engineering 23rd - 25th of October, 2014 Craiova, Romania, 271-278.